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THE DRIFT OF THE ETHER

By *R. K. Young*

OF all the terms used in science the ether is the most difficult to understand. For centuries its use has been confined to those engaged in teaching or in research. The great interest aroused by the theory of relativity and the extraordinary publicity which has been given to this most abtruse subject has made the word *ether* familiar everywhere. The thing itself is as great an enigma as ever.

The ether is that substance which is supposed to fill all space where there is no matter and also the spaces between the molecules, atoms and electrons within matter. The idea that space between the solid bodies was filled with some medium has long prevailed. To the ancient natural philosophers, the principle that "nature abhors a vacuum" was sufficient justification for supposing its existence, and another reason for believing in the reality of the ether was the notion that the planets were floating or swimming in a fluid.

However the only ether which has survived the older metaphysical conceptions is that one which we meet in Huygens' explanation of the propagation of light. Light is a form of energy which is transmitted from one point to another, from one place on the earth to another, or from the sun to the earth, or from the most distant parts of the universe. Energy can be transmitted in three ways: (1) There may be a direct material connection between the source and the point of delivery of the power. This method is illustrated by the lever, the line-shaft, the belt. (2)

There may be an actual transfer of matter, as illustrated by the rain, by a rifle bullet or any projectile. (3) Lastly, there may be a wave motion in a medium. If the smooth water surface in a pond is disturbed at one side, waves are set up in the water and the motion of the particles communicates itself to adjoining particles so that the disturbance is transmitted to the other side. If the air is disturbed by the stroke of a hammer the air in the region about the point of impact is compressed. The region of compression travels outward in all directions and delivers energy on our ear drums, which we interpret as sound. These three methods are the only ones we know for the transmission of power. Huygens' explanation of the propagation of light by waves is therefore based on analogy, and if there are waves we must invent a medium in which the waves exist. That medium is the ether.

The ether must have certain properties which may be made the subject of experiment. It readily permeates matter. If a tube more than thirty inches long, closed at one end, is filled with mercury and inverted with the open end in a basin of mercury, the height of the column will drop to about thirty inches, leaving a vacant space in the top of the tube. The vacant space is transparent and we must suppose is filled with the light carrying medium. If the tube is inclined, the mercury column rises to the top of the tube, apparently pushing out the ether which, however, immediately returns on restoring the tube to the upright position. The ether must be very non-resisting or mobile, for the planets and other heavenly bodies move through it at very great velocities and seem to suffer no apparent loss of speed. Even the comets, which are themselves probably one thousand times less dense than ordinary air, seem to suffer no retardation. The ether is probably quite elastic also, for it is shown in physics that the velocity with which a wave is propagated is equal to the square root of the elasticity divided by the density,

$$V=\sqrt{e/d}$$

where e is the elasticity, d the density, and V the velocity of light. The velocity of light has been measured and is very approximately 3×10^{10} cms. per second. Hence the elasticity of the ether multiplied by $1/d$ must equal 9×10^{20}. This relation is usually taken

to mean that the density is very low rather than that e is large. From other considerations Lord Kelvin took the upper limit of the elasticity as 1/100, but the value is not known. The larger we make e the greater must be the density in order that the equation may hold. The ether is also very transparent, for the light comes down to us from the very distant astronomical bodies, such as the star clusters, without suffering absorption.

In 1725 an English astronomer, Bradley, made a discovery which was called the *aberration of light.* He discovered that every star's position was displaced forward in the sky in the direction in which the earth was moving. The following account of this discovery is taken from Grant's "History of Astronomy."

Up to about the year 1700 the facts revealed by the invention of the telescope and the discovery of gravitation established beyond all doubt the truth of the Copernican theory, but the absence of any observed change in the positions of the stars when observed from the opposite ends of the earth's orbit was a serious objection. Astronomers in various ages had attempted to observe this phenomenon but had failed. One of the methods which seemed to be best adapted for this purpose was that of observing stars whose zenith distance was small, since the effects arising from any uncertainty in the value of the refraction are thereby avoided. In 1725, Molyneux, an amateur astronomer, resolved to undertake a series of observations of γ Draconis, which passed very close to his zenith, and he had a large zenith sector erected at Kew, his place of residence. On the third of December, 1725, the instrument was employed for the first time in determining the position of the star. Similar observations were also made on the fifth, eleventh, and twelfth. It was deemed unnecessary to make any further observations until the season of the year should arrive when the earth was in the opposite side of its orbit. It was, therefore, more from curiosity than any other motive, according to his own statement, that Bradley, who was then at Kew, was induced to observe the star on the seventeenth of December. He found the position of the star to be somewhat more southerly than it appeared to have been early in December. Both Bradley and Molyneux suspected an error in the observations, and re-observed it on December the twentieth, when, to their great sur-

prise, they discovered that it had advanced still farther south. This motion could not be due to parallax for it was in the wrong direction. The star continued to advance toward the south until the beginning of March, 1726, when it attained a distance of twenty seconds of arc from its original position, and in April it appeared to be returning north. In June, it again passed the meridian at the same distance from the zenith as it did in the beginning of December. It continued to move northward until September, when its displacement toward the north was as great as it had been toward the south in March. By December, 1926, it was again back in its original position, having performed its period of displacement in the same time that the earth revolved about the sun.

It was a considerable time before the explanation of the phenomenon was obtained, but at length the idea occurred to Bradley that the finite propagation of light combined with the motion of the earth in its orbit was the cause. We can understand the explanation with the least effort by an analogy. If you are out in a quiet rainstorm, when the rain is coming down in lines perpendicular to the surface of the earth, you will notice that as long as you are standing still you will see the drops of rain coming straight down, but that the moment you move forward they seem to come to meet you, and it is necessary to hold your umbrella somewhat in advance in order to keep the rain off. The similar thing is true in the case of light, only here the velocity of light is very large and the angle that the rays are deflected through is small. The analogy is not very complete because the rain drops are material bodies while we believe light to be waves in a medium. The same explanation will hold, however, if you consider the ether to be left behind by the earth or to remain at rest while the earth moves through it.

The hypothesis that the ether is not affected by the presence of matter introduces the greatest difficulty to the physicist on account of the phenomena of refraction. Refraction is explained on the wave theory by a diminished velocity for light in the refracting medium, which is hardly consistent with the view that the ether carries the light unaffected by the molecules of the substance. The wave theory of light had not been established at the time of

the discovery of the aberration of light and, in fact, nearly one hundred years later, mathematicians like Laplace and Poisson, favoured the corpuscular theory. The discovery of interference by Young in 1800 and the investigations of Fresnel and others led to the abandonment of the corpusculary theory, and aberration had to be made consistent with the laws of refraction. Fresnel, who, with Arago, was the chief exponent of the wave theory, was led to the conclusion that the ether inside bodies moved with a fractional part of the bodies' motion, its velocity being represented by the expression

$$\frac{n^2-1}{n^2}.V$$

where n is the index of refraction and V the velocity of light in free space. Fizeau, some twenty years later, using an apparatus which had in principle been suggested by Arago, tested this theoretical result and found it to be true. The experiments of Michelson and Morley, however, when they let a beam of light fall on a half-silvered surface where it divided, one half being made to pass through a tube in which there was a current of water flowing, the other part being made to pass through a tube whose water flowed in the opposite direction, showed that the velocity of light was not affected by the motion of the water. The experiment was performed in 1886, and at this time we think the difficulties connected with the explanation of the phenomena of aberration had been pretty well met.

To summarize, aberration demanded an ether which did not move with matter when the latter was suffering translation, and Michelson's experiment with the flowing water proved this. The experimental results of Fizeau, which showed a diminished velocity of light in media depending on the index of refraction and Fresnel's theoretical results that the molecules modified the ether in their immediate neighbourhood enabled the refraction phenomena to be explained. However, experiments had been made by Klinkerfues, and later by Airy, on the aberration of light in a telescope tube, filled with water and they showed no change in the coefficient of aberration. This result demanded that the ether be dragged along to a certain extent by the water in the tube.

A contradiction existed, therefore, between the aberration experiments of Airy and the flowing water experiments of Michelson and Morley. To test further the so-called drift of the ether, Michelson devised another experiment which was first performed in 1881 but was repeated much more carefully in 1887. It is usually known as *The* Michelson and Morley experiment. As the literature of the subject is not very recent, and is probably unavailable to the bulk of the readers of the JOURNAL, we give a short summary of their work which is taken from the *Philosophical Magazine* for December, 1887.

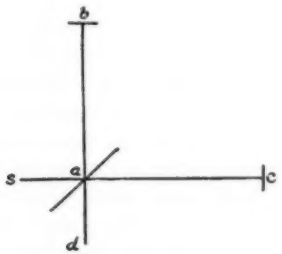

Fig. 1. Source Stationary.

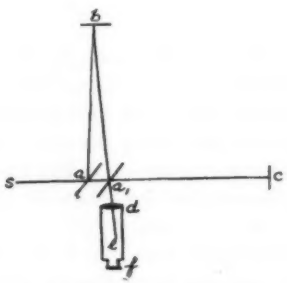

Fig. 2. Source moving.

Diagrams illustrating the path of the light.

In Figure 1, let *sa* be a ray of light which is incident upon a half-silvered surface inclined at 45°, so that the ray is partially reflected along *ab* and partially transmitted to *ac*. The two rays are returned by mirrors at *b* and *c*. The two returning beams are also reflected and refracted at *a* again, and if the paths *ab* and *ac* are equal the two rays interfere along *ad*.

Suppose the whole apparatus moves in the direction of ac, and that the ether remains at rest, the directions and distances traversed by the rays will be altered. The conditions of observation are represented in Figure 2. The ray which was reflected to *b* will have traversed the path aba_1 and the transmitted ray will have traversed the path aca_1.

Let V = velocity of light,
v = velocity of translation of the apparatus,
D = distance ab or ac Figure 1,
T = time light occupies to pass from a to c,
T_1 = time light occupies to pass from c to a_1.

Then

$$T=\frac{D}{V-v} \text{ and } T_1=\frac{D}{V+v}.$$

The whole time of going and coming is

$$T+T_1=2D\frac{V}{V^2-v^2},$$

and the distance travelled in this time is

$$\left[2D.\frac{V}{V^2-v^2}\right]V.$$

This may be written

$$2D\left[1-\frac{v^2}{V^2}\right]^{-1}=2D\left(1+\frac{v^2}{V^2}+\frac{v^4}{V^4}+\text{ etc.}\right)$$

Neglecting terms of the fourth order this reduces to

$$2D\left(1+\frac{v^2}{V^2}\right).$$

The length of the other path aba_1 may be readily computed from the fact that a_1 is to $2D$ as v is to V and hence $ab+ba_1$ is evidently $2D\left(1+\frac{v^2}{V^2}\right)^{\frac{1}{2}}$. This may be expanded as before, and, neglecting the higher powers, we get

$$2D\left(1+\frac{v^2}{2V^2}\right).$$

The difference in the paths of the refracted and reflected rays is therefore Dv^2/V^2, and if the whole apparatus be turned through 90°, the difference will be in the opposite direction.

A sketch of the apparatus used by Michelson and Morley is shown in Figure 3, while figure 4 gives a plan of the same apparatus. The optical parts proper of the apparatus rested on a square slab of stone about 6½ feet square and 12 inches thick. The stone in turn was fastened to a wooden annular ring which floated in a basin of mercury supported on a brick and cement pier. It will

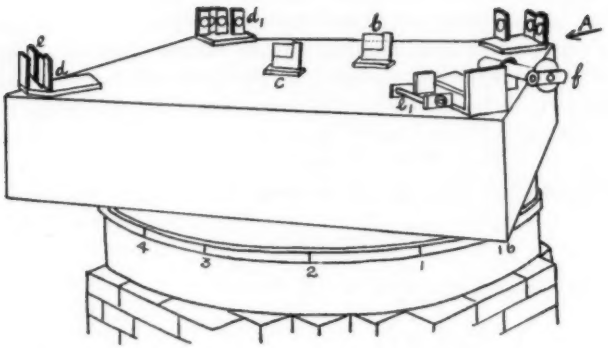

Fig. 3. Perspective view of Michelson's apparatus.

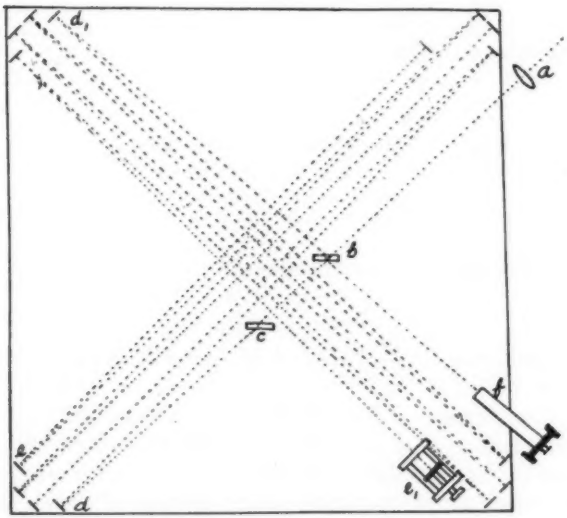

Fig. 4. Plan of apparatus, showing the path of the light in the interferometer.

be noticed that the formula for the difference in the two paths involves D, and in order to make this as large as possible a system of multiple reflections was employed. The light entered at A, passed through a lens and fell on b so as to be partly reflected to d_1 and partly transmitted to d; the two pencils followed the paths indicated in the figure, *bdedbf* and *bd*$_1$*e*$_1$*bf*, respectively, and were observed by the telescope f. Both f and a revolve with the stone. The second mirror c was a plane piece of glass and was placed in the path of one of the pencils to compensate for the passage of the other through the same thickness of glass. The total length of path was about 37 feet or 11 metres. When the paths had been adjusted to equal length and the interference fringes were seen in the telescope, the observations were conducted as follows: Around the cast-iron trough were 16 marks, shown in Figure 3. The apparatus was revolved very slowly (one turn in 6 minutes) and after a few minutes the cross wire of the micrometer was set on the best of the interference fringes at the instant of passing one of the marks. The reading on the screw head was noted and a very slight and gradual impulse was given to maintain the rotation of the apparatus; on passing the second mark the same process was repeated and this was continued for 6 complete revolutions. It was found that by keeping the apparatus in slow uniform motion, the results were much more uniform than when the stone was brought to rest for every observation.

Readings were made on several days near noon and also at 6 p.m. Theory shows that if the velocity of the earth's motion entered with its full effect they should have observed a displacement of about 0.4 fringe. The actual motion of the earth in space is the resultant of its orbital motion and of the motion of translation of the solar system as a whole. The latter component being unknown it is impossible to predict any *expected* relative motion of the earth and ether. The interferometer is affected only by that component of the earth's total motion which lies in the horizontal plane of the apparatus. This plane is perpendicular to gravity at the location and is continually changing with respect to space as the earth rotates. Michelson and Morley announced their conclusion as follows: "Considering the motion of the earth in its orbit only . . . the observations show that the relative motion of

the earth and the ether is probably less than one-sixth the earth's orbital velocity and certainly less than one-fourth." While the combination of the orbital velocity with the solar motion affects the predicted displacement, their conclusion seemed amply justified and was accepted as showing a negative result. The ether moves with the earth in its orbital velocity about the sun.

This result is not in harmony with the explanation of the aberration of light. To remove the difficulty several hypotheses were put forward, the most acceptable being probably that of Fitzgerald-Lorentz, who suggested that matter contracts in the direction of its motion. They supposed that the block of stone and the rest of the apparatus in the Michelson-Morley experiment shortened in the direction of translation by an amount sufficient to compensate for the expected increase of path due to the motion of the ether. This is not very hard to imagine when one realizes that the accepted view of matter makes it consist of very small particles, quite remote from one another, which might be crowded together slightly in the direction of motion. However, by using different substances for the support it was shown to be the same for two substances, and Lord Rayleigh suggested that any contraction should be accompanied by double refraction phenomena, which his experiments and those of Brace later failed to detect.

The next noteworthy experiment in the subject was made by Professor O. J. Lodge, in another attempt to detect the dragging effect of matter on the ether. The apparatus consisted of a pair of circular plates 3 feet in diameter. These plates were mounted with their planes parallel and 1 inch apart on a vertical axis, and were set spinning at as high a speed as they would safely stand without flying to pieces. If the ether in the space between the spinning discs is dragged around with them, then a pencil of light travelling around between the discs in the direction of motion would be expected to traverse the space with a greater velocity than a beam travelling in the opposite direction. To test this, a parallel beam of light was divided into two parts by a half-silvered mirror, and the two halves of this split beam were reflected by fixed mirrors, in such a way that they passed in opposite directions round and round the space between the spinning disks. The beams could thus be made to traverse a distance of 30 or 40 feet

between the disks and then be allowed to enter a telescope, where they interfered and produced fringes. When due precautions were taken to avoid the disturbing effects of air currents thrown off by the disks, no indication of a shift was obtained. The experimental results were in harmony with what we would expect from the aberration of light but contradicted the Michelson-Morley experiment.

All the results so far obtained have been consistent in failing to detect the ether. They would be in harmony if the ether did not exist, but we would then be confronted with the problem of accounting for the propagation of light. Recent experiments seem to show that the ether has at last been detected and is a real thing.

Lord Kelvin expressed the conviction in 1900 at the International Congress of Physics that Michelson's experiment should be repeated with a more sensitive apparatus. Professor D. C. Miller, in collaboration with Professor Morley, constructed an interferometer about four times as sensitive as the one used in the first experiments, having a light path of 224 feet. The instrument was used in the basement of the Case School of Applied Science in Cleveland in 1904 and 1905. The result showed that the relative motion of the earth and ether was very small.

In the autumn of 1905 the interferometer was removed from the laboratory to a site in Cleveland at an altitude of 300 feet above Lake Erie and free from the obstruction of buildings. Here in 1905 and 1906 they got a positive effect of about 1/10 the earth's orbital velocity. They were not quite satisfied with the result, however, fearing that temperature changes in the instrument were the cause and they desired to test the thing at still higher elevations. The experiments were resumed in March and April, 1921, at the Mount Wilson Observatory in California at 6000 feet altitude.

At the Mount Wilson station about 5000 single measures of the ether drift were made at various times of day and night. The apparatus being the same as used in 1904 and in principle the same as that of the Michelson-Morley experiment. Each observation gave, for a specified time, the magnitude of the displacement of the interference fringes, together with the azimuth of the line of sight in which the displacement was a maximum. Since the light

in the interferometer travelled along one arm and back again the observations gave only the line in which the drift occurred but not the sign.

Figure 5 shows the observations of April, 1921. Here the arrows indicate the observed direction and the magnitude of the drift, the arrows being located around a circle at points corresponding to the sidereal times of observation. The observations were next repeated when the metal parts had been shielded from temperature changes by cork, and the results were unaltered.

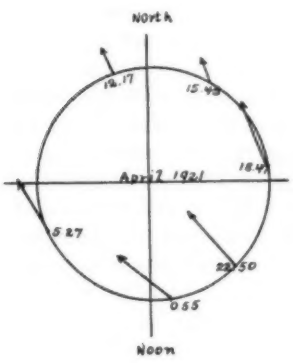

Fig. 5.

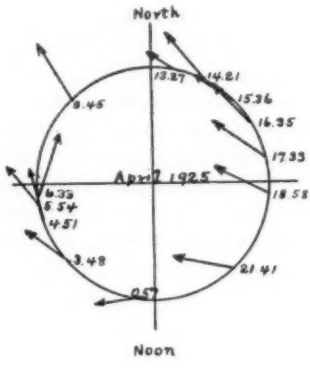

Fig. 6.

The arrows indicate the observed relative drift of the observer and the ether.

As a next trial the instrument was partially rebuilt, getting rid of any metal parts which might have a magnetic effect; but the result of 900 observations showed an ether drift of exactly the same direction and amount as previously obtained. At the same time many variations of conditions were tried, such as reversing the direction of rotation, making the rotation fast or slow, putting the frame under an added load, with the float level or tilted with the assistant walking around near or far from the apparatus while the measures were being made. The results were unchanged.

As a further test of the reliability of the apparatus ti was dismounted and taken to Cleveland, and many trials made there to

determine the effect which the conditions of observation had on the result. Notable among these were those to test the effect of inequalities in temperature. Electric heaters were placed in close proximity to the apparatus, and while they caused a slow drift of the fringes they did not produce a periodic shift. The net result of all these experiments was to confirm in a very satisfactory manner the result obtained nearly forty years earlier, namely, that near the surface of the earth there was no relative drift of the earth and the ether.

In 1924 the apparatus was again taken to Mount Wilson to repeat the experiment. In 1921, the apparatus had been located on the very edge of a deep canyon and it was feared that air currents

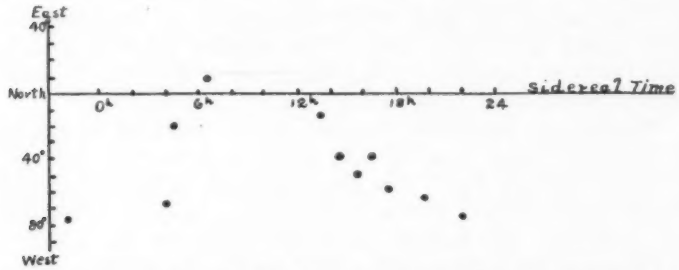

Fig. 7. Diagram showing the direction of the drift with respect to the points of the compass at various sidereal times.

might have produced a disturbance. A new site was chosen and the interferometer house erected with its orientation as regards the ridge changed 90° from that of 1921. The results of 275 measures are shown in Figure 6. The corresponding ether drift is consistent in direction and magnitude with the results obtained before and shown in Figure 5.

There is a specific relation for a given latitude between the observed azimuth of drift and the sidereal time of observation. Observations at different sidereal times should show different azimuths and all observations at the same sidereal time should show the same azimuth. Sixteen hundred observations were combined into eleven sets at various sidereal times, with the result shown in Figure 7. The ordinates of the graph are azimuths and

the abscissae sidereal times. The points lie on a curve of the kind that would correspond to some definite direction and velocity of ether drift.

Summing up the results of Miller's work at Mount Wilson during the years 1921 to 1925 we are led to the conclusion that there is a drift of the ether of about 1/3 the orbital velocity of the earth, and a drift which varies with the altitude is also suggested. We have now positive evidence of a medium which carries the light, and that the velocity of light relative to the earth varies when the earth moves in the medium. It is true that a satisfactory explanation of aberration cannot be given and that the results obtained with the water-filled telescope are also unexplained. The writer of this article is not well enough versed with the theory of relativity to say just what effect there will be on that doctrine, but it would appear that some of the premises must be altered, since the basic experiment which suggested it is shown to have different results from those formerly held to be true.

Readers will remember that one of the predicted results of the relativity theory was the shift of the stars near the sun due to the gravitational field. The shift was shown to be there by the English astronomers in 1919 and confirmed at subsequent eclipses very strikingly. We have to find an explanation for this shift.

The whole study of the drift of the ether is a beautiful example of the scientific method of research. In the beginning there were the two theories, the corpuscular and the wave theory. These suggested experiments which led to new discoveries, and each experiment and research was suggested and based on results obtained previously. It does not matter so much whether the wave theory, the corpuscular theory or the theory of relativity represents a reality, for at least all have been productive in suggesting lines of research which have led to discoveries. There is a great satisfaction in harmonizing the results of experiments by some general law. Science is not yet in a position to formulate this general law for the relation of the light to the ether, but at the rate progress is being made something definite should evolve in the years soon to come.

THE ORBITS OF FOUR SPECTROSCOPIC BINARIES WHICH SHOW BOTH SPECTRA

By W. E. HARPER

IN the course of the past two or three years spectrograms have been obtained incidentally of a number of binaries. Of the four here treated two were discovered at other observatories and two at our own. In all four cases the spectrum of the fainter component is measurable, though its intensity relative to that of the main component varies very widely from star to star and, moreover, this ratio varies in the same star, being seemingly dependent upon the positions of the components in their orbits. Full details of these orbits with graphs and reproductions of spectra will appear in Volume III, No. 10 of the *Publications* of this observatory, but it is thought a summary of the results in popular form may be of interest to readers of the JOURNAL.

Least-squares solutions were, as usual, carried through in each case, and the orbital elements finally accepted are given in the table at the end. With one or two exceptions all spectra were made with the single-prism, medium-focus camera attached to the 72-inch telescope and giving a dispersion at $H\gamma$ of 29 angstroms per millimetre. The plates used were Seed 30 and of late the Eastman 40. All stars are of F-Type and the plates have invariably been measured on the micrometer engine.

63 Geminorum

The star was discovered to be a spectroscopic binary at the Lick Observatory in 1922, and 39 plates secured here in 1923, 1924, and the present year are made the basis of this investigation of its orbit. While the mass of the main component is only one and one-quarter times, yet the intensities of its spectral lines are two or three times that of the secondary. In spectra of this type and

of this dispersion, where numerous lines are crowded together in the spectrum, it is somewhat difficult to assign a value for the relative intensities of the component lines. The few cases of isolated lines indicate such a value, which ratio, moreover, satisfies a number of others when allowance is made for the superposition of neighbouring lines. There would seem, however, to be some slight evidence that this ratio was not constant, as if the lines of the secondary increased in strength when that component in its orbit was approaching the earth.

The components revolve about each other in almost circular orbits in a period slightly under two days. The semi-amplitudes of velocity variation are 95 and 117 km. respectively.

σ^2 *Coronae Borealis*

This star was discovered to be a spectroscopic binary at Mount Wilson in 1914. During the years 1922, 1923, 1924 and 1925 a total of 74 plates have been secured here. This number, which is much larger than usually required, was necessitated by the fact that the period of nearly eight days which was indicated by the first two years' observations gave rather poor agreement for many of the observations. While the general trend of the observations seemed to indicate an eight-day period, yet the agreement was extremely ragged; and additional observations last year and this were secured to see if some adjustment of the period would not improve the agreement. Considerable time has been expended in testing out possible periods but a value of 7.974 days, as originally suggested, has had to be adopted.

The spectra are of the numerous line F-type, one being slightly stronger than the other so that distinction can be made between them. The semi-amplitudes of velocity variation for the components are only 60 and 68 km/sec. respectively, and thus for over half the period the lines are hopelessly confused in spectra of single-prism dispersion. Some reluctance is felt at accepting a period which gives a probable error of a plate of 6 km/sec. for an F-type star, but the explanation of the poor agreement undoubtedly lies in the overlapping of the spectral lines so numerous in this type of star.

H.R. 7267

This star was discovered to be a spectroscopic binary by W. H. Christie from spectra made here in 1923. Thirty plates since made form the basis of the determination. The component spectra are about of equal intensity and from 10 to 15 lines of each component were measured on those plates showing the lines resolved. The semi-amplitudes of velocity variation are identical, each being 86.0 km/sec. Thus the masses are identical also, the minimum value for the combined mass being 2.5 times that of the sun. The probable error of a plate is of reasonable magnitude, being ±2.9 for component I and ±3.7 km/sec. for component II.

H.R. 8257

This star was discovered by the writer to be a spectroscopic binary in 1923. Twenty-three of the thirty-two plates secured show the lines of both components. The period is 12.21 days and, unlike the other three stars discussed here, this orbit is quite elliptical, the eccentricity being .318. Here again the component

DATA OF FOUR SPECTROSCOPIC BINARIES

Element	63 Gem.	σ^2 Cor. Bor.	H.R. 7267	H.R. 8257
α	7h 21.8m	16h 10.9m	19h 04.2m	21h 30.9m
δ	+21° 39′	+34° 07′	+16° 42′	+27° 46′
V. Mag.	5.27	5.76	6.46	6.35
Type	F5	F8	F5	F3
P	1.93265 days	7.974	4.812	12.21
e	.002	.081	.073	.318
ω_1	104°.84	90°.0	59°.16	46°.79
ω_2	284°.84	270°.0	239°.16	226°.79
γ	+24.38 km./sec.	−10.63	+8.80	−43.17
K_1	94.56 km./sec.	60.12	86.03	51.95
K_2	116.76 km./sec.	68.77	86.04	65.24
T	J.D. 2,423,430.048	3,216.694	3,630.622	3,710.068
$a_1 \sin i$	2,513,000 km.	6,570,700	5,677,400	8,269,800
$a_2 \sin i$	3,103,000 km.	7,516,000	5,678,000	10,385,200
$m_1 \sin^3 i$	1.05⊙	0.94⊙	1.26⊙	0.97⊙
$m_2 \sin^3 i$	0.85⊙	1.07⊙	1.26⊙	0.77⊙
r_1	4.75 km./sec.	6.0	2.89	3.2
r_2	7.03 km./sec.	6.6	3.71	4.7

spectra, while similar in kind, differ greatly in intensity, the main one being on the average nearly twice the strength of the secondary. As far as can be judged this ratio also varies slightly, the secondary when approaching the earth having its spectrum lines strengthened as compared with the phases when it is receding from the earth.

Dominion Astrophysical Observatory,
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STATISTICAL STUDIES OF STARS WITH SPECTRA IN CLASS Be

By RALPH H. CURTISS

STATISTICAL examinations of class B stars with hydrogen emission lines in their spectra were begun by the writer more than a decade ago, partly to assist in the planning of observing programs of these objects. Reports of these studies have been published from time to time.[1] The present paper was submitted in preliminary form to the American Astronomical Society in September, 1923, but was published only in abstract, since it was known that additional data were about to be made available. The publication of the last volume of the Henry Draper Catalogue[2] and of the latest reports of the Mount Wilson Survey of class Be spectra[3] now mark an epoch at which statistical results of a relatively complete and enduring character may be reached in the study of class B stars with emission lines.

NUMBER

The number of stars classified in this group now reaches two hundred and thirty—or approximately one for each thousand stars in the Henry Draper Catalogue. In addition to this total more than sixty cases of class B spectra with suspected hydrogen emission are on record, some of which will be found to belong in the list. More than eighty additions to the class Be group have been made in the last five years through the survey of Merrill, Humason, and Burwell at Mount Wilson.[4] Others have been added in the Henry Draper Catalogue to the numerous Harvard discoveries.

There is of course some uncertainty in drawing the exclusion line when making up the list of class Be stars. The seven class O stars on one end and the five class A stars on the other, as shown

in Table 1, appear to indicate the extremities of the distribution curve. The nineteen stars classed simply as Be almost certainly come within the group. It is probably wise to include also the seventeen unclassified P Cygni stars. So far as these objects have been assigned letters they range from O6 to B8. Four faint stars whose spectra are termed peculiar are included provisionally in Table 1, column 14, but are not used in further statistical studies in this paper. The two stars fainter than magnitude 9.25 in column 11 of Table 1 are classed as Ap. Neither is in the Henry Draper Catalogue. One, in the Greater Magellanic Cloud, may have been intended for D.M. $-69°$ 401 (H.D. 37,836) which is of P Cygni type. The other is D.M. $-56°7537$, a star in galactic latitude $-16°$ but with Hβ emission visible. B.D. $+10°1172$ (N.G.C. 2247) and H.D. 200,775 (N.G.C. 7023) are not included in Table 1, though it is possible that they should be, since they are found in a Mount Wilson list[3] of class Be stars. A few stars from whose spectrum hydrogen emission has faded are included in Table 1. Class O stars are included only when hydrogen emission is present. Wolf-Rayet stars are excluded. F and G emission stars are known but their status is uncertain.

Of the probable number of hydrogen emission line stars in class B within convenient exposure range of instruments now in use some idea can be gained. That the Harvard list was incomplete was well recognized, and was brought out through the remarkable success of the Mount Wilson survey, including the Hα region. Suffice it to say that the hydrogen emission is frequently variable and sometimes difficult. The Mount Wilson survey was fairly exhaustive, since it was felt that only about ten per cent. might be added to the known lists of bright line stars in class B by reworking the same areas in the same way. But these areas did not include about eighty-seven degrees of the milky way in the southern sky from galactic longitude 230° to 317°. This region will yield some twenty additional stars with the Mount Wilson methods if the density of occurrence of these objects in the rest of the milky way is maintained here. Also the strip along the galaxy covered at Mount Wilson was narrow in places. Again some few stars with variable emission have been missed, and these will be added slowly to the total. If to the present total we add

twenty stars for the region of the galaxy, not accessible from Mount Wilson, twenty-five stars to be found by reworking the areas now accounted for, twenty stars that may be found outside of the Mount Wilson areas, assumed to extend the full length of the milky way, and fifteen stars with variable emission now faint, we obtain *a total of about three hundred so-called class Be stars within reach of survey instruments as they have been used, supplemented by slit spectrographs on brighter stars.* Given a very long time interval

TABLE 1. DISTRIBUTION OF CLASS Be STARS BY MAGNITUDES AND SPECTRAL CLASSES

Class (1)	O5-O9 (2)	B0 (3)	B1 (4)	B2 (5)	B3 (6)	B4 (7)	B5 (8)	B8 (9)	B9 (10)	A0-A2 (11)	P Cygni (12)	Be (13)	Pec. (14)	Total (15)
Mag.														
-4.25	0	2	0	3	7	0	7	2	0	1	0	0	0	22
4.26-5.25	1	1	5	6	12	0	6	3	0	0	(2)	0	0	34
5.26-6.25	3	2	2	6	9	0	6	2	1	0	0	1	0	32
6.26-7.25	1	8	5	8	8	1	2	6	1	1	(2)	0	0	41
7.26-8.25	2	4	6	8	8	1	3	0	1	0	1, (1?)	3	0	37
8.26-9.25	0	7	3	6	4	0	0	2	0	1	4, (1)	9	1	37
9.25-	0	1	1	1	0	0	0	1	0	2	12	6	3	27
Totals.....	7	25	22	38	48	2	24	16	3	5	17	19	4	230

NOTE—The upper left and lower right-hand corners of the classified section of Table 1 are not rich in stars. This is true of the former region because stars of exceptionally great mass only are normally found there, and of the lower right-hand region of Table1 because late spectral type and intrinsic faintness are unfavourable to the presence of emission lines.

in the future hydrogen emission might appear in a large number of class B spectra, but this uncertain factor, which may be offset by disappearance of emission lines in other B stars, is not considered here. The group is probably in relatively stable numerical equilibrium.

Slit spectrographs will reveal the presence of weak hydrogen emission in additional class B stars. Bright Hβ in some stars cannot be seen on the Harvard plates, whereas it is clearly visible on slit spectrograms made at Mount Wilson and Ann Arbor. It is not possible to predict the possibilities of future discovery in this direction. Probably, however, we can derive the maximum ex-

pectancy in this connection if we assume (1) that the ratio of emission line stars to all stars of class B0-B5 averages one to seven for all magnitudes considered, the value found for the brighter stars which have been more completely studied with the slit spectrograph; (2) that among further discoveries the proportion found outside of the range B0-B5 will remain the same. With these assumptions the predicted number of class Be stars would reach about 350 for magnitudes brighter than 8.26. At present about 165 class Be stars of this magnitude range are known. The number, 350, is probably too great. To accept it we must admit a large discovery factor dependent upon magnitude and very great relative efficiency of the slit spectrograph as compared with the objective prism instrument. However, the incompleteness of our knowledge of slit spectra in the Hα region leaves open a possibility of discovery of some magnitude.

Distribution by Spectral Division

The distribution of class Be stars by photometric magnitudes and spectral divisions is shown in Table 1. The spectral classes and magnitudes determined at Harvard, chiefly included in the Henry Draper Catalogue, have been adopted for a majority of the stars counted in this table. However, the classifications made at Mount Wilson with slit spectrograms were used when available in preference to objective prism results. The Mount Wilson reclassifications of class Be spectra move the group on the average toward the top of the sequence, *i.e.*, into earlier divisions. The effect is small, however, averaging only 0.6 of a division for forty-two reclassified stars and vanishing for the brighter stars. This small difference is probably due to the fuller detail of the slit spectrograms, especially in registering the helium lines.

In Table 1 a preponderance of stars in the spectral range B0-B3 is at once evident. Stars to the number of 133 are found in this range and 55 fully classified stars outside of it, and only 45 in the rest of class B. When it is noted that the divisions, B4, B6, B7, and B9, are used little if at all, the reduced frequency of occurrence of these stars in the later divisions of class B is more fully realized. Probably some of the stars in division B3 would find their way

into B4 if these two divisions were equally favoured by the classifiers. Keeping this in mind it is evident that the Be stars occur with greatest frequency at division B2.5 or thereabouts.

The concentration of Be spectra in the earlier divisions of the spectral sequence is especially striking when compared with the distribution of all stars over classes O and B and division A0. This comparison is made in Table 2, for stars brighter than 8.26, using the Harvard counts of objects in the Henry Draper Catalogue for B and A0 stars. The number of O stars is estimated from Plaskett's enumeration of lists collected by him.[4] Wolf-Rayet stars are not included, in this estimate. Under emission line stars in Table 2, as elsewhere in this paper, only those with hydrogen emission are included though other emission lines may be present.

TABLE 2. RATIOS OF EMISSION STARS BY CLASSES

Class	H. D. Cat. Stars	Emission Line Stars	Ratio
O5-O9	55	7	1:8
B0-B5	1996	136	1:15
B8	1604	13	1:123
B9	2752	3	1:917
A0	6320	1	1:6320

In Table 2 it is evident that *conditions become more favourable to the occurrence of visible emission lines as we proceed upward in the spectral sequence.* The ratio of O5-O9 stars is noteworthy.

Distribution by Spectral Class and Magnitude

The distribution curves over the spectral divisions *for the various magnitude groups* of classified stars in Table 1 vary in an interesting way with magnitude. The curve for stars brighter than 4.26 would appear to be fairly symmetrical about a maximum somewhere between B3 and B5. As we proceed down the magnitude divisions in Table 1, the distribution curves become asymmetric with a sharp rise from class O and a slow fall along the later divisions of class B. As stated above the maximum of the distribution curve for all class Be stars is near division B2.5. But for the brighter stars this maximum appears to occur between divisions B3 and B5, and for the fainter stars it shifts toward the earlier

divisions, reaching a division near B1 for the magnitude group 8.26-9.25, below which limit the number of classifications is too small to be considered. The seven stars in classes O5-O9 and the few stars in classes A0-A2 represent the normal outlying section of the distribution curve of the class Be group.

The characteristics of the distribution curves of Be stars over the spectral divisions, brought out in the last paragraph, are sufficiently pronounced to be significant. The form of these curves depends on the following factors at least: (1) The variation with spectral divisions of conditions favourable to the occurrence of visible emission lines (the earlier the spectrum the more favourable are conditions for the visibility of emission on the average); (2) the distribution of all O, B, and A stars among the spectral divisions; (3) uncertainties of classification increasing with fainter spectra; (4) a discovery factor due to increasing difficulty in recognizing emission in fainter stars, reducing especially the relative number of discoveries of fainter stars of later spectral division, in the spectra of which emission is intrinsically weak.

It is difficult at present to segregate these different factors. The first alone would favour a distribution curve rising sharply from division A2 to B5 and thence more gradually to O5 (see Table 2), while the second gives a curve rising sharply from O5 to early B and thence more gradually to A2. The combined effect of these two factors, varying as their product, is responsible for much of the character of the observed distribution curves. The effect on these curves of errors in classifications is probably not large. The discovery factor is undoubtedly accountable in some measure for the increased asymmetry of the distribution curves for fainter magnitudes. It should be pointed out that the proportionately smaller number of the fainter Be stars (see Table 3) might be accounted for and removed, in part at least, if we were to assume that all this increased asymmetry were due to the discovery factor of the last paragraph, and that future discoveries with more suitable equipment would so abound in fainter Be stars of later spectral divisions that the distribution curves for fainter magnitudes would be made symmetrical like those for the brighter stars. It seems hardly probable however that this will be the case. It is probably true of the distribution curves of Be stars

over the spectral divisions that the variation in form of such curves with apparent magnitude is partly due to the smaller chance of discovery, especially in fainter spectra, of Be stars of later spectral divisions, but also partly *due to a real scarcity of faint Be stars in the later divisions in which Be stars are found.* And this scarcity is due to the fact that such stars average intrinsically faint and are of late spectral class in the group, conditions unfavourable to the visibility of emission.

Distribution by Magnitudes

The totals by magnitudes in the last column of Table 1 do not show the expected increase for the fainter magnitudes. This condition is brought out in Table 3 in which stars with spectra ranging from B0 to B5 inclusive are considered. The totals for these stars classed by magnitudes in column 2 are taken from a paper by Shapley and Cannon,[5] *The Distribution of Stars of Spectral Class B.* The divisions are made at the quarter magnitudes because the spectral classifications in this part of the sequence are selectively incomplete and somewhat uncertain below magnitude 8.25. The number of these stars known to have hydrogen emission through lists published up to 1925 is found in the next column and the ratio in column 4. With fainter magnitudes there is a pronounced decrease in the proportion of these stars known to have emission lines. Quite certainly there is a discovery factor operative here due to our less complete knowledge of fainter

TABLE 3. PROPORTION OF STARS OF SPECTRAL CLASSES B0-B5 HAVING HYDROGEN EMISSION LINES

Magnitudes	B0-B5	B0e-B5e		B0e-B5e More than Hα bright	
	Number	Number	Ratio	Number	Ratio
-5.26	346	49	1- 7.1	45	1- 7.7
5.26-6.25	367	25	1-14.7	23	1-16.0
6.26-7.25	564	32	1-17.6	30	1-18.8
7.26-8.25	719	30	1-24.0	30	1-24.0
Totals.....	1996	136		128	

spectra especially in the Hα region. Recent discoveries have made the proportionate decrease for emission line stars in class B with increasing faintness less prominent, though the ratios here given are strongly in the same direction as those derived for the first twelve hours of right ascension in Volume III of the *Detroit Observatory Publications*, where all stars known and suspected up to November, 1920, only, were included.

That element of the factor affecting the discovery of these bright line stars, depending on our limited knowledge of the Hα region, may be partly removed by confining our counts to stars having at least one emission line in the photographic region. In column 5 of Table 3, counts of stars with at least Hβ bright are given with ratios of such numbers to the total of class B0-B5 stars for each magnitude division. The relatively greater frequency of

TABLE 4. NUMBER OF HYDROGEN EMISSION LINES WITH SPECTRAL CLASS AND MAGNITUDE IN CLASS Be SPECTRA

Magnitudes	O5-O7	B0-B1	B2	B3-B4	B5-B6	B8-B9	A0-A2	All Classes
-4.25	..	4.0	5.5	3.6	2.0	1.5	1.-	3.0
4.26-5.25	1.-	3.5	3.0	2.6	2.8	2.0	..	2.7
5.26-6.25	2.7	2.8	1.8	2.9	2.2	2.3	..	2.5
6.26-7.25	2.-	2.4	2.5	2.4	2.5	2.3	1.-	2.4
7.26-8.25	5.-	2.7	3.1	2.7	2.7	2.-	..	2.8
8.26-	..	2.5	2.9	2.0	..	2.5	3.-	2.5
All Mag.	2.7	2.7	2.8	2.7	2.4	2.2	1.7	2.64

emission line stars among the brighter magnitudes is not materially changed when counts are restricted to the photographic region. This test is not conclusive, however, for in many cases bright Hα was responsible for the discovery and Hβ emission was observed thereafter.

That there is a discovery factor dependent on faintness is quite certain; and it is important to consider whether it may be accentuated by reduced average number (and brightness) of the hydrogen emission lines in fainter stars. To study this and other points Table 4 has been prepared. This gives the average number of emission lines found in these stars, tabulated by magnitudes and spectral divisions. In the last column the average number of

emission lines for all classes is not found to diminish in an important degree if at all with fainter magnitudes. In the earlier divisions of class B an effect of this kind appears to be brought out, but some of the means are not long and our greater knowledge of the region of shorter wave-length in brighter spectra is a factor here. However, it is quite probable that among the fainter stars those with brighter and more numerous emission lines have been found first on the average, and when the fainter stars have been more completely surveyed their hydrogen lines will average less numerous and relatively fainter, referred to the continuous spectrum, when compared with the same features in brighter stars. However this may be, undoubtedly something more than a discovery factor is needed to account fully for the greater relative number of known emission line spectra among the brighter stars of class B. It appears, as Merrill[19] and the writer[1] have pointed out in previous papers, that *the stars which are intrinsically brightest in this class tend more strongly to develop visible emission in their spectra.*

Number and Intensity of Emission Lines

The important relation between the number and the intensity of hydrogen emission lines in class Be spectra may be expressed conveniently by the use of the Mount Wilson intensities[3] for the lines as compared with the corresponding number of these emission features as noted by various observers. On the Mount Wilson intensity scale a strong emission line is denoted by the number 4; medium strength by 3; the weakest ordinarily observable by 2; and a very weak line by 1. On the basis of eighty-five stars, for which the data are known, the comparison between average intensities of the Hα emission and the number of hydrogen emission lines is given in the first two columns of Table 5. The same comparison for the Hβ line is made in the third column of this table, using the more homogeneous data of Table V of the Mount Wilson publication above cited. Above the range of the table there were two stars, one with five and the other with six emission lines of hydrogen recorded. In each case the strength of Hα emission was four. If we reverse the argument of Table 5 and go back again to the data, we find that when Hα emission is strong (intensity 4) the

average number of emission lines observed is 3.5; when of medium strength (intensity 3), 2.6; when weakest ordinarily observed (intensity 2), 2.1; and when very weak (intensity 1), 1.9. Obviously *the intensity of the Hα and Hβ emission lines increases on the average with the number of hydrogen emission lines in class Be spectra* and this is true in general of emission lines in the Balmer series of hydrogen. These results constitute an important extension of Campbell's rule[6] that the bright hydrogen lines in these spectra are those of greater wave-length; and the intensities of these bright lines decrease as we approach the violet—a rule that has been found to be essentially inviolable.

TABLE 5. INTENSITIES AND NUMBERS OF EMISSION LINES

Number	Intensities	
	Hα	Hβ
4	3.3	3.2
3	3.1	2.1
2	2.7	1.2
1	1.7	...

Spectral Class and Strength of Emission Lines

The data in Table 4 may be used again to bring out the variation of the average strength of the emission lines in class B stars with spectral divisions. The fact, established numerically above, is made use of, namely, that on the average the intensity of the hydrogen lines varies with their number in any spectrum of the class here considered. And the number of lines is tabulated rather than their intensities because the data on the former are considerably more extensive. For stars brighter than 5.26 there is a decided increase in the number of emission lines with earlier spectrum, but for the fainter stars this effect disappears. For all magnitudes combined there is a maximum of 2.8 lines visible at class B2, but with no great differences in the numbers from class O5 to B4. For divisions later than B4 the emission lines of hydrogen become progressively fewer until at class A a somewhat uncertain average of only 1.7 lines is reached. Of the stars in the Be group those having early spectra in class B tend to develop more and

stronger emission lines of hydrogen. And it appears reasonable to presume that this effect will be as pronounced among the fainter stars as among the brighter ones when our data are more complete, for among the fainter stars those with stronger emission on the average are being found first.

As a check on the results of Table 4 we may use Hα and Hβ intensities as determined at Mount Wilson for 76 and 79 stars respectively. In Table 6 these intensities are averaged against spectral divisions. Weak means depending on two or three stars are enclosed in brackets. The other averages depend on nine or more stars each. The class O means are too weak both here and in Table 4 to receive much weight. For both the Hα and Hβ lines the greater strength in early class B is notable and in good agreement with results in Table 4.

TABLE 6

Class	O5-O9	B0-B1	B2	B3-B4	B5-B6	B8-A2
Hα Int.	(2.0)	2.9	3.0	2.9	2.8	2.4
Hβ Int.	(1.3)	1.4	1.5	1.4	(1.5)	0.8

The P Cygni Group

The total of P Cygni type stars in column 12, of Table 1, reaches twenty-two, with an additional star, of magnitude 7.4 and class O6e, that is included provisionally. The enclosed numbers in this column refer to stars that are classified by letters in other columns of the table. These stars are duplicated in this column in order to assemble all known objects in this important subgroup. Other stars on investigation will probably find their way into this column; and when the spectra now designated as "P Cygni type" are assigned letters they will scatter over the earlier columns of Table 1. The five now classified range from Class O6 to Class B8. The star, P Cygni, is of Class B1eq. The preponderance of faint stars in this group is notable.

Galactic Distribution

It is well known that the stars in spectral divisions B0-B5 in common with many other objects tend strongly to cluster toward

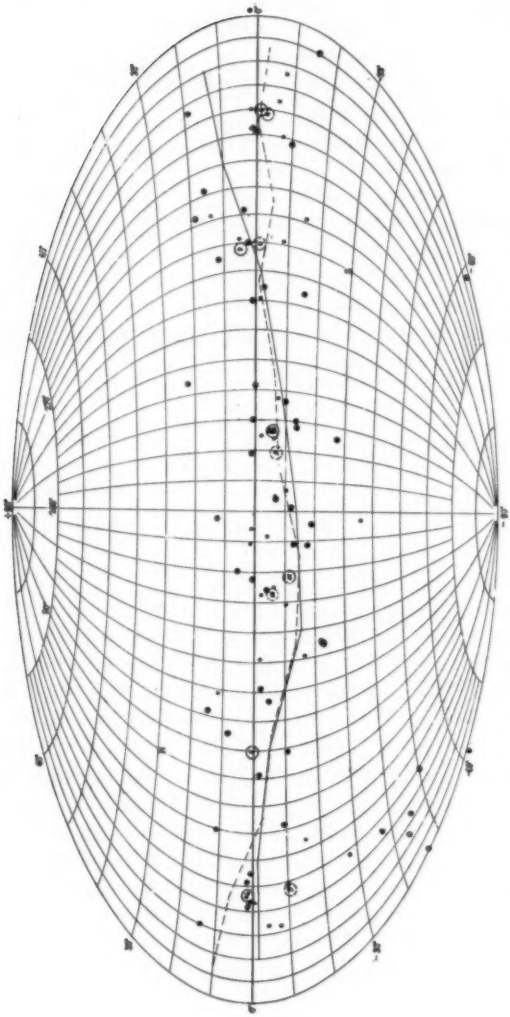

Chart 1. Galactic Distribution of Class Be Stars of Magnitudes Brighter than 6.26.

the galactic equator. This is true similarly for stars in the spectral divisions B0e-B5e. To bring this condition out clearly the stars of this bright line group have been plotted on Aitoff's equal areas projection of the sphere, using galactic co-ordinates.

The first chart contains stars of magnitudes brighter than 5.26, represented by the larger dots, and stars between magnitudes, 5.26 and 6.25, represented by smaller dots. The full lines connect Shapley and Cannon's median points for all class B0-B5 stars brighter than 5.26 magnitude, and the broken line similarly for stars of magnitude, 5.26 to 6.25. The full circles are median points for emission line stars brighter than magnitude 5.26, and the broken circles for magnitudes, 5.26 to 6.25. An outstanding feature of this chart is the group of bright stars in the Capricornus-Aquarius-Pisces-Pegasus region with centre in galactic longitude, 30°, and latitude, −45°. Kappa Draconis stands apart in the same way in northern galactic latitudes. These seven stars were not included in the formation of median points for emission line stars. The dip due to the local cluster of class B stars reaching a maximum galactic distance in longitude, 170°, is present in the emission line stars though in less degree than for all class B0-B5 stars.

The second chart contains stars in the three groups of magnitudes 6.26-7.25, 7.26-8.25, and fainter than 8.25, designated by large dots, circles and small dots respectively. The full lines connect Shapley and Cannon's median points for the first and the broken lines for the second magnitude group. The emission line stars cluster together so well that median points are not needed to help the eye.

The emission line stars in the second chart do not follow the median points for all class B0-B5 stars as well as might be expected. The dip for the brighter stars of normal spectra in the neighbourhood of galactic longitude 170° is inverted if anything for the emission line stars. This may be due to our less complete knowledge of the southern skies, but should be kept in mind. It is interesting to note that the stars plotted here tend above the galactic equator from longitude 110° to longitude 200°, and below it from the latter longitude to 320°.

A number of stars of P Cygni type are designated on the charts by the letter P. In addition to those thus marked there are nine

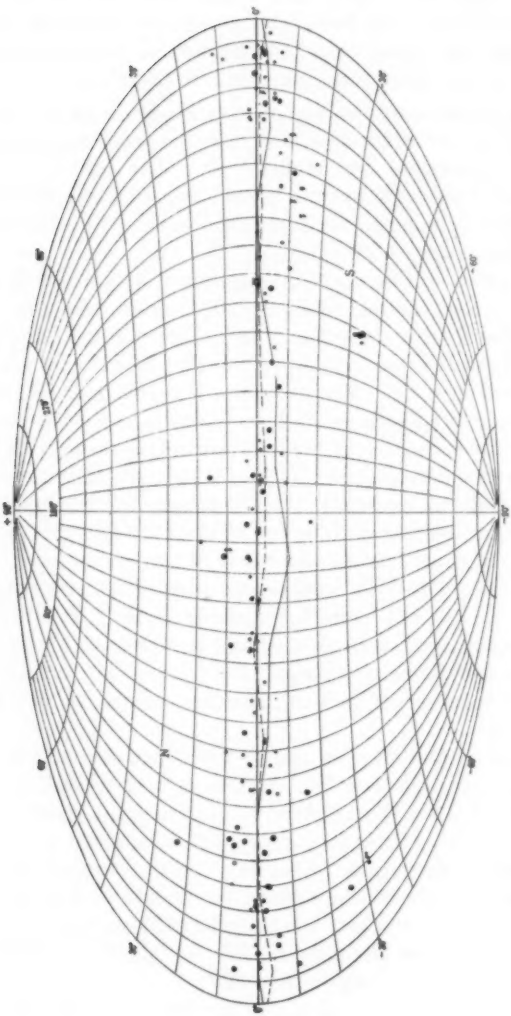

Chart 2. Galactic Distribution of Class Be Stars of Magnitudes Fainter than 6.26.

such objects, and two other hydrogen emission stars that may be of this class in the Greater Magellanic Cloud (Gal. Long. 247°; Gal. Lat. 33° South) forming a conspicuous group on the chart of fainter stars. It is well known that these stars are more or less gregarious as the chart indicates. The thirteen galactic P Cygni stars, among which fainter stars predominate, have an average galactic distance of 5°.0 and a median galactic latitude of −2°.9.

A glance at these charts reveals the fact that the class Be stars frequently occur in groups. If the two charts were combined this would be still more conspicuous. Two of these groups have

TABLE 7. GROUPS OF CLASS Be STARS

Region	Equatorial Co-ordinates		Galactic Co-ordinates	
	Right Asc.	Decl.	Long.	Lat.
1. Pleiades	53°	+24°	135°	−23°
2. Aur	78	+37	135	+ 2
3. Nebecula major	80	−68	247	−33
4. Gem-Ori-Tau	87	+23	155	0
5. Pup-CMa	109	−25	205	− 5
6. Vel-Car	158	−60	255	− 2
7. Sco	260	−37	322	− 2
8. Sgr-Sct	275	−15	345	− 2
9. Cyg	304	+36	42	0
10. Cap-Aqu-Psc-Peg	335	0	30	−45

been mentioned above. Ten are tabulated in Table 7, with others omitted that might well be mentioned. Some, but by no means all, of these groups stand out in Shapley and Cannon's charts of B stars.[5] Merrill, Humason, and Burwell[3] point out that the third, fifth, seventh, and ninth of these groups are in regions rich in Wolf-Rayet stars. The fifth and eighth regions also include such objects.

Comparing the distribution of emission line stars of the different magnitude groups in class Be, it is quite obvious that these stars, in common with the other B stars, occur in higher concentration in low galactic latitudes when fainter. This is brought out numerically in Table 8. Here the average galactic distances and median galactic latitudes are tabulated for the emission stars in class Be,

and for all stars in divisions B0-B5, by magnitudes. The extraordinary companion of Omicron Ceti is not included in Table 8 and is not shown on the charts.

For both emission and non-emission stars the average galactic distance decreases progressively with fainter magnitudes from about 14°.5 for the brighter stars to five or six degrees for the stars averaging about eighth magnitude. But the emission line stars average closer to the galactic equator than other B stars for all magnitudes fainter than 5.26. And this would be true of all magnitudes in Table 7 were it not for cluster 10 of Table 6, an outstanding group of six bright Be stars. Though the closer search

TABLE 8. AVERAGE GALACTIC DISTANCES AND MEDIAN LATITUDES OF CLASS Be AND CLASS B0-B5 STARS

Magnitudes	Average Galactic Distances		Median Latitudes	
	Class Be	Class B0-B5	Class Be	Class B0-B5
	°	°	°	°
-5.25	14.7	14.4	−7.0	−4.0
5.26-6.25	7.9	11.6	−5.3	−4.7
6.26-7.25	6.1	8.2	−1.1	−3.2
7.26-8.25	5.1	6.2	−1.0	−1.5
8.26-	4.1	...	−1.5	...

NOTE—Group of eleven stars in the Greater Magellanic Cloud not included.

near the galactic equator for emission lines in faint spectra is to be reckoned with here, it seems probable that some of this effect is real. If so, it may mean that more stars from distant regions of the Milky Way are included among the fainter emission stars than among the fainter normal stars in class B of the same apparent magnitude. In other words *the Be stars may average far away and intrinsically bright for their class*, a suggestion discussed elsewhere in this paper.

The median galactic latitude decreases progressively from larger negative values for the brighter stars to smaller negative values for the fainter ones. This effect seems to be more pronounced for Be stars than for normal B0-B5 stars, beginning with greater latitude for the brighter stars, and drawing closer to the galactic equator for the fainter ones. The greater median latitude of brighter Be stars as compared with normal B stars is more than

removed by omitting the six stars of the remarkable group 10 of Table 7. The fainter emission line stars, although including representatives of later spectral classes, cluster toward the galactic equator as closely as or more closely than the normal B0-B5 stars. This raises again the possibility that *the Be stars are intrinsically bright in their class*, for it suggests that among the B stars of a given magnitude the emission stars are farther away.

Luminosity, Parallax, and Motion

Our data relative to the brightness of individual Be stars are limited but, with a remarkable exception, they assign them high luminosities as far as they go. The super-giant, α Cygni, at the lower spectral extreme for the group probably develops hydrogen emission because of conditions associated with its very high luminosity. Nine P Cygni stars in the Large Magellanic Cloud have an average absolute magnitude of −6.0. Of these the brightest S Doradus, with a median absolute magnitude of −8.9 is one of the most luminous stars known.[7] A magnitude of −3.28 is derived for Gamma Cassiopeiae by Rasmuson[8] in his study of moving clusters. Mitchell's[9] trigonometric parallax of Kappa Draconis corresponds to an absolute magnitude of −2.6 and Schlesinger's of c Persei to −1.2. The companion of Omicron Ceti is the remarkable exception to the norm of its class. With a B8ep spectrum and an absolute magnitude of +6.0 there is reason to suspect that systemic association with a luminous companion introduces abnormal conditions which may affect a spectrum profoundly.

In the Be spectra we find "c" characteristics which point to great luminosity. The narrow lines which often characterize giant stars are represented here in the absorption reversals which are usually found in the hydrogen emission and in some cases in the metallic unless the emission itself is sharp. It is only a step from the narrow lines of Alpha Cygni to those of Zeta Tauri and thence to Gamma Cassiopeiae as representative Be stars.

The study of the motions of these bodies from the standpoint of radial velocities is beset with especial difficulties. Spectral variations and absence of measurable spectral features in any numbers

make quantitative determinations difficult and slow in many cases. When Campbell's[10] important study of 225 class B stars was made, only five Be stars with well determined velocities were included. Adams and Joy[11] derived spectroscopic parallaxes for only four Be stars, raising the question whether these stars are exceptional in their behaviour. With the publication of the results of Frost's extensive programme on B spectra,[12] material may be at hand to study the spacial motions of these objects. It was hoped that data would be available in this connection from the large store of spectrograms of these stars at Ann Arbor, but the discovery of a number of variable spectra[13] has caused delay.

Of especial interest are the group motions and luminosities derived from the statistical studies of Katpeyn[14] and Rasmuson.[8] In his study of three moving clusters Rasmuson determined

TABLE 9. ABSOLUTE MAGNITUDES IN MOVING CLUSTERS

Cluster	Pleiades		Perseus		Sco-Cent	
	Magn.	Class	Magn.	Class	Magn.	Class
Be Stars.....	−0.61	B5	−1.51	B2.0	−0.96	B3.8
B0-B5 Stars.....	+0.28	B5	−0.03	B3.7	−0.46	B3.0

absolute magnitudes of numerous B stars sixteen of which had emission lines. A comparison of emission and non-emission stars is given in Table 9. In each cluster the emission stars average brighter.

Kapteyn's statistical studies of helium stars furnish data for comparisons of total proper motion and luminosity. The results of averages for 25 Be and 182 B stars of magnitude 4.25−6.0 between 150° and 360° galactic longitude are found in Table 10. For the emission and normal stars the average spectral division is essentially the same, which places the two groups on a similar footing in this respect. The average apparent magnitude of the Be stars in Table 10 is 0.06 of a magnitude brighter than that of the B stars, whereas the Be group is absolutely brighter by 0.34 magnitudes. Combining this result with those from moving clusters in Table 9 we may conclude that the Be stars considered here average at least half a magnitude absolutely brighter than the

B stars. This is the difference according to Adams and Joy[11] between the magnitudes of diffuse and sharp line stars of B2 or B3, and hence is significant in this connection. The slower total proper motion of the emission stars is quite marked, suggesting that they are farther away than normal B stars of the same spectral class and apparent magnitude, are more luminous and probably more massive.

Still longer means are available if we use all stars in the Preliminary General Catalog of Boss. As a preliminary test and since the distributions of the emission and non-emission B stars

TABLE 10. COMPARISON BETWEEN NORMAL AND EMISSION B STARS OF MAGNITUDES 4.25-6.0

Class	Div.	100μ	Abs. Mag.	App. Magn.	Stars
		"			
B0e-B5e	3.37	1.96	−0.47	5.08	25
B0-B5	3.36	2.71	−0.13	5.14	182

TABLE 11. COMPARISON BETWEEN PROPER MOTIONS OF NORMAL AND EMISSION B STARS

Mag.	$100\mu\alpha$		$100\mu\delta$		Stars	
	B0-B5	B0e-B5e	B0-B5	B0e-B5e	B	Be
	s	s	"	"		
-4.25	0.239	0.238	2.53	2.64	103	19
4.26-5.25	0.169	0.114	1.62	0.90	199	30
5.26-6.25	0.146	0.099	1.59	1.16	137	16

are similar, a direct comparison of the proper motions in α and δ of the two groups (emission and non-emission stars) is of value. This comparison is made in Table 11. In this table for stars brighter than 4.25 mag., the motion of the two groups is similar. This is noticed also in the total proper motions for the stars of class B studied by Kapteyn. The dispersion of these brighter stars in magnitude and their wide distribution over the sky makes comparison less reliable. But for stars fainter than 4.25 the comparisons are more reliable, and *the slower motions of the Be stars are very strongly shown, a condition pointing to higher luminosity or greater mass or both.*

Mass

High luminosity in Be stars is probably associated with great volume and mass for the spectral class. However direct evidence of relatively great mass among Be stars is not so easy to find. The B2 e component of Beta Lyrae gives us one datum of value. The irregularity in the velocity curve of the B8 star in this system during eclipse, found by Rossiter,[15] enables us to fix the duration of eclipse and to obtain a ratio of the masses of about 1 to 9. This mass ratio corresponds to a mass of the emission star of 15.3⊙. The writer's orbit[16] of this star from Hβ emission gives it a mass of 22.7⊙. Probably the true mass is between these two values. Evidence based on real motion is next to seek in studying the masses of Be stars.

Evidence from Radiation Theory

It is interesting now to consider the light that may be thrown upon the problem of the probable nature of Be stars from the standpoint of radiation theory. Twenty years ago Schuster proposed a valuable theory[17] to account for the occurrence of emission lines in stellar spectra. He suggested that such emission lines would appear if in a star's atmosphere (1) scattering of radiation were predominant over absorption, and (2) the gradient of radiation intensity were slight. Martin[18] has examined this theory on the basis of more recent developments in the physics of radiation, and finds that true absorption and not scattering predominates in any mass of gas, unless it contains such a preponderance of free electrons over atoms as to make quantum absorption a rare event. Thus it follows that Schuster's criterion for the appearance of an emission line, so far as it concerns scattering, is invalid, unless there is some reason why an atmosphere should allow scattering to be more effective, even though the mass scattering coefficient is small. In the sun there is a narrow transition layer with a steep pressure gradient below and radiative equilibrium above, and in this layer scattering reaches its maximum comparative effectiveness. Further, in highly luminous bodies of great mass and low surface gravity, with a close balance between radiation pressure and gravity, the layer of comparatively effective scattering, so narrow in the sun,

is greatly expanded. In such a case, with high ionization conducing to scattering, bright lines may appear according to Schuster's first condition. Again, Martin points out that, in such stars of high luminosity and great mass, Schuster's second condition of a low radiation intensity gradient will be fulfilled, for the very gradual dying away of pressure in the atmosphere of these stars will flatten the radiation gradient.

It is a striking circumstance that statistical results point to the very conditions in Be stars which Schuster and Martin find favourable to the appearance of emission. We have seen that hydrogen emission occurs with greatest proportional frequency at the top of the spectral sequence where ionization is at its height. Also in several ways it has been pointed out above that these emission stars average highly luminous in their class, and with this high luminosity probably go great mass and volume.

While early spectral class and high luminosity are undoubtedly conditions favourable to visibility of emission, if they are necessary conditions they are evidently not always sufficient ones. Thus a star like Pleione may lose its emission lines with no other observed change in light. Some other factor or factors appear to be operative whose character is not known. Orbital effects, expansion due to light pressure in excess of gravitation with or without subsequent contraction, other pulsations, and friction with nebulous matter are all possible unknown factors. Needless to say the study of the spectrum variables among Be stars gives greatest promise of a solution for this problem.

Summary

With the conclusion of important surveys at Harvard and Mount Wilson, the discoveries of class B spectra with visible hydrogen emission have reached a total of 230. Of these, 188 are assigned to spectral divisions, ranging from Oe or O6 to A2. The other forty-two, averaging faint, are classed as Be, Ae, P Cygni, or in rare cases, peculiar.

Three hundred so-called Be stars are probably within reach of survey instruments as they have been used, supplemented by slit spectrographs on brighter stars. For stars brighter than 8.26 an upper limit of 350 in class Be is provisionally set up.

Class Be stars occur with greatest frequency on the average at division B2.5, or thereabouts, with greatest numbers in the range B0 to B5. The percentage of emission stars in the spectral divisions increases markedly from the lower limit of the group near A2 to the top of the spectral sequence. The distribution curve over the spectral divisions for stars brighter than 4.26 is fairly symmetrical about a maximum somewhere between B3 and B5. For fainter stars these distribution curves become asymmetric, with a sharp rise from class O, and a slow fall along the later divisions of class B. Fainter stars in the later spectral divisions of the emission group are probably relatively scarce and with relatively weak emission lines. Seven stars in class O, and five in divisions A0 to A2, represent the outlying sections of the distribution curve of the Be group.

With brighter magnitudes there is a pronounced increase in the proportion of B stars known to have emission lines. Allowing for a discovery factor dependent on magnitude, accentuated perhaps by reduced average brightness of the hydrogen emission lines in fainter stars, it still appears that *stars which are intrinsically brightest in class B tend more strongly to develop visible emission in their spectra.*

The intensity of the Hα and Hβ emission lines increases on the average with the number of hydrogen emission lines in Be spectra; and this is obviously true in general of emission lines in the Balmer series.

Of the stars in the Be group, those having early spectra in class B tend to develop more and stronger emission lines of hydrogen. This effect is pronounced for the brighter stars, and probably will be shared by the fainter stars when the data are more nearly complete. For all magnitudes combined there is a maximum of 2.8 hydrogen emission lines visible in division B2 e.

The Be stars show the high concentration toward the galactic equator characteristic of normal class B. Ten groups are notable, of which three are at considerable galactic distances. Some, but not all of these groups, stand out in Shapley and Cannon's charts of normal B stars. Considered by magnitudes, the Be stars show some departures from the galactic distribution of normal B stars that may be significant.

The galactic distances of the fainter Be stars average less, and their median latitudes approach the galactic equator more closely than those of B stars. This may mean that the Be stars of any magnitude average farther away than the normal B stars, and are for this reason to be considered intrinsically brighter.

The proper motions of the Be stars average slow for their spectral class and apparent magnitude. Studies of motions and magnitudes of B stars as a class and of moving clusters, unite in assigning relatively high luminosities to the Be stars. Notable individual examples are S Doradus, α Cygni, and γ Cassiopeiae. Probably this high luminosity is associated with great mass. It is significant that these characteristics of high luminosity and great mass, together with high ionization (early spectral class), are those which according to radiation theory are favourable to the visibility of emission lines in stellar spectra.

Ann Arbor, Mich.,
December 30, 1925.

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VARIABLE STAR OBSERVING FOR AMATEURS

By R. M. Petrie

THE study and observation of variable stars seems to be particularly fitted to amateur astronomers, and therefore a brief description of the methods employed might be of interest to the general reader. No special training is required for this work and, with a little practice, accurate eye-estimates can be made by almost anyone. No telescope is too small for use on these stars, and in some cases binoculars can be used to advantage. Quite recently a new variable was discovered in Vulpecula by an observer of variable stars, Mr. W. F. H. Waterfield, Nakusp, B.C. Thus results of true scientific value can be obtained in this work, yielding a satisfaction not always found in amateur efforts.

There have been several different classifications of variable stars, but the most widely used, perhaps, is that due to Prof. E. C. Pickering. The following shows his system, and was taken from "An Introduction To The Study of Variable Stars", by Caroline E. Furness. There are five main classes as follows:

Class 1. *Temporary or new stars.*—These are stars which blaze out suddenly, becoming very bright in a short time, and then fading out into a very faint star or becoming invisible. They have only one maximum. Their spectra are peculiar in that they contain bright and dark bands of hydrogen and helium, side by side, the dark bands being displaced toward the violet end of the spectra, while the bright bands are displaced toward the red end.

Examples of this class are Nova Aquilae, discovered in 1918, and Nova Pictoris, discovered in 1925.

Class 2. *Long period variables.*—These stars have fairly definite periods of variation, generally about one year in length. They vary over a considerable range in magnitude, sometimes becoming naked-eye stars at maximum and very faint at minimum.

Their range in magnitudes and periods of variation are not hard and fast, but are subject to minor fluctuations. Their spectra are peculiar at maximum, showing bright hydrogen lines, and their type is usually that of Harvard Class M. A star typical of this class is Mira (Omicron Ceti), discovered to be a variable in 1596. This star has a period of roughly 332 days, and has a range in magnitudes of from 1.7 to 9.5. At present writing Mira is visible to the unaided eye, being between the second and third magnitudes. χCygni is also a good example of Class 2 variables. It has a period of 406 days, and a range in magnitude of from 4.5 to 13.5. Thus at maximum it is nearly 4,000 times as bright as at minimum.

Class 3. *Irregular variables.*—The stars in this class have a variation so irregular that no period can be determined. These variables have in general spectra of the types M and N. αHerculis with a range of 0.8 magnitude and type M7 is an example of this class.

Class 4. *Short period variables.*—This group contains stars ranging in period from a few hours to 45 days. It is subdivided into two groups, the Cepheid variables, and those of the βLyrae type. δCephei, an example of the first subdivision, has a fairly rapid rise to maximum with a decline to minimum taking about twice as long as the rise. The βLyrae type have a primary and secondary minimum with one maximum. The Cepheids have spectra of classes F or G, and the βLyrae variables are usually found in the early classes B or A.

Class 5. *Algol type variables.*—The light of Algol (βPersei), which is typical of this class, is characterized by a steady maximum with a rapid descent to, and ascent from, minimum. The spectral peculiarities place these stars generally in classes A and F. It might be here noted that recent measures with photo-electric cells have shown that Algol variables have a slight secondary minimum, and that other considerations would justify placing them in the βLyrae subdivision of class 4.

The foregoing classification will give a general impression of the known behaviour of variable stars, and will show that there is a wide field for speculation and research regarding these bodies. It is with class 2, however, that we are concerned at present.

The new and irregular stars do not offer much scope to the amateur, and the stars of classes 4 and 5 are best studied with the aid of delicate photometers and photo-electric cells, such as are usually found only in well equipped observatories. But the long period variables having a gradual but large range in brightness, are splendid objects for study with small visual telescopes, such as are usually found in the possession of amateurs, all the data required in order to obtain the light curve of these stars being the magnitudes to the nearest decimal place and the time to the nearest hundredth of a day.

The method of estimating the magnitudes of the variables is by comparison with stars of constant brightness in the same field. Blue-print charts on different scales of the region surrounding the variable are issued by the Harvard College Observatory. On these charts the right ascension and declination of the variable are given, and if the telescope is fitted with circles the field can be immediately located. If no circles are provided the position of the variable can be noted on a star chart with respect to some known star, and the region swept with a low-power finder until the variable is located. For this purpose the writer has found that the star charts showing only visual stars are preferable.

When the variable has been found and identified by means of stars in the same field, the next step is to estimate its brightness. In order to do this, recourse is again had to the blue-print charts. On them the magnitudes of upwards of a dozen stars, surrounding the variable, are given to the nearest tenth, and by comparison with these stars the magnitude of the variable can be estimated without great difficulty.

After the observation is taken, the estimated magnitude, local standard time, the date, the instrument used and any other interesting information are recorded. The observations are reported once a month, and are published by "The American Association of Variable Star Observers" in "Popular Astronomy". In this manner data are amassed by a number of observers regarding these stars, and their periods of light variation, if regular, can be determined.

As an example of observed stars a table has been formed comprising recent observations of two stars, made by the writer. The

first of them, R Cygni, is a variable with a period of 426 days and a light range of 7.9 magnitudes, going from 5.9 to 13.8. These observations show a good range, the first five observations showing that the star, either due to faintness or adverse conditions of seeing, was invisible, in which case the faintest star seen in the field was recorded. The later observations show the star becoming brighter until it is almost a naked-eye object. At present writing this star is becoming fainter again. The other star, U Cygni, does not show such a change in brightness, but it is typical of the type of observations which may be expected in this work. It is a variable with a period of 464 days, ranging from the 6th almost to the 12th magnitude.

These observations were made for the most part with a six-inch Newtonian reflector, loaned to the writer by the "American Association of Variable Star Observers". The instrument is mounted equatorially and is without setting circles, a refractor of 2″ aperture being used as a finder. It might be of interest to state here that the mirror for this telescope was figured by Prof. E. C. Pickering for use in variable star work.

The table is self explanatory. The times of the observations are all Pacific Standard Time, p.m. In the column headed designation is given the Harvard number of the star. This number consists of six figures, the first four giving the right ascension of the star to the nearest minute, the last two giving the declination to the nearest degree. Thus R Cygni, whose number is 193449, is 19 hrs, 34 m. in right ascension, and 49 degrees north in declination. If the Harvard number is underlined or italicized the declination is understood to be south of the equator. By using this system, the number of the star, besides distinguishing it, gives information about its position sufficient to enable all but the large instruments to pick up the field.

The observation of variable stars, if only for a short time, will give valuable experience to the amateur. There is scarcely a better way of becoming familiar with the naked-eye stars and the constellations than by searching them for variables. One also gains an insight into the methods of scientific mensuration, which is always useful. As one continues in this work and as the observations increase, the interest of the observer becomes heightened,

and it becomes an absorbing study to follow out the light variations of the observed bodies.

In conclusion I would say that if there are any persons, with or without telescopes, who wish to do some useful astronomical work and who are perhaps at a loss as to the best employment of

Star	Designation	Julian Day	Time P. S. T.	Estimated Magnitude
R Cygni	193449	2424320	10.35	<10.9
"	"	324	10.40	<11.3
"	"	329	10.28	<11.3
"	"	330	10.20	<10.9
"	"	338	10.05	< 9.6
"	"	347	9.50	12.1
"	"	349	10.05	12.0
"	"	350	9.35	11.8
"	"	361	9.45	11.5
"	"	368	9.05	10.9
"	"	369	8.50	10.5
"	"	395	8.25	9.8
"	"	415	7.35	7.8
"	"	432	6.50	6.7
"	"	435	7.35	6.5
"	"	458	7.50	6.8
"	"	480	6.00	6.8
U Cygni	201647	2424338	10.10	< 9.2
"	"	347	10.10	10.0
"	"	350	9.30	9.5
"	"	368	9.10	9.8
"	"	395	8.30	8.8
"	"	415	7.40	8.9
"	"	432	6.50	8.7
"	"	458	8.05	8.0
"	"	481	8.15	7.0

their time, they would be well advised to join the "American Association of Variable Star Observers".

The "Association" is anxious to obtain new members, and anyone interested can obtain full information from Prof. L. Campbell, Harvard College Observatory, regarding the observation of variable stars. By thus engaging in some definite line of work they will derive pleasure and profit therefrom, at the same time aiding science in the advancement of human knowledge.

Victoria College,
Victoria, B.C.,
December 30, 1925.

REVIEW OF PUBLICATIONS

Publications of the Lick Observatory, Vol. XV.—Meridian Circle—By R. H. Tucker

THIS volume is the fourth of the Lick Observatory Publications to be devoted to meridian work, the previous ones having been volumes IV, VI and X. It covers the meridian circle observations made in the years 1906 to 1923 inclusive, and embraces some fifteen different programmes, most of which were special series of observations undertaken for various purposes at the request of different individuals or institutions. The great majority of the observations, some nineteen thousand in number, as well as the reductions, were made by Mr. Tucker in person. It forms the culmination of a lifetime of work of one of the best known of meridian astronomers, whose results and conclusions have come to be regarded as authoritative.

In keeping with Tucker's well-known conservatism, the Repsold meridian circle at the Lick Observatory has never been equipped with the travelling-wire micrometer or reversing eye-piece, which have now come to be regarded as well-nigh indespensable adjuncts to a modern equipment; in fact, during the thirty years of his regime, there have been almost no changes in the instrument or auxiliary equipment. Especially where the observations have been carried on practically throughout by a single observer, this is in some respects an advantage, since the observations during this whole period form a consistent series which for length and systematic unity have probably not been approached elsewhere.

As those familiar with his writings might be prepared to expect, the author's treatment of the various problems considered, and his analysis of the results, are almost meticulously thorough. If a general criticism might be made it is that in some cases rather too much has been taken for granted as to the reader's knowledge of the particular methods followed in the making, grouping and analysis of the observations, so that sometimes considerable study is re-

quired to verify, and even to reveal, the exact bearing of the results deduced.

Leaving aside the lists of stars observed for particular purposes, some of which were fundamental and some differential, the outstanding problems treated are those of the latitude and its variation, refraction, and sunrise and sunset effects on transits. Preliminary results on these have been already published, mostly in Lick Observatory Bulletins.

The latitude results are particularly interesting from their bearing on the earthquake of 1906, during which adjacent points on opposite sides of the San Andreas fault were relatively displaced as much as 20 feet; this fault is about 20 miles west of the observatory. The weighted means of the two groups of latitude observations, before and after the earthquake, are identical. Each group treated separately, however, gives a rate of gradual increase of latitude, though these rates, judged from their probable errors, may have no real meaning. Treating them as real, and extrapolating to the date of the earthquake, there is indicated a movement of twelve feet to the south. Leaving aside the point that such a movement would undoubtedly have wrecked the observatory, it is remarked by the author that the changes indicated have probably no real significance.

The correction, applicable at the Lick Observatory station, to the refraction constant of the Poulkova Tables is given as —0.″ 20 tan Z.D. for the night hours and +0.″ 28 tan Z.D. during the day. The whole change is considered to take place near sunrise and sunset, between the times when the sun is three hours above the horizon and one hour below, the change being assumed uniform during that period. It is stated that the observations in 1909 and 1910 at San Luis, of which Tucker had charge, confirmed the above result both in magnitude and epoch. Recent fundamental work at Poulkova is quoted as establishing for that observatory the difference "day minus night" as —0″. 14 tan Z.D.; if the noted sign is correct this appears to be in the opposite direction. Quite possibly this whole matter is closely connected, at any particular station, with the form and nature of the building housing the instrument. If differences of temperature inside and outside the building exist, a condition which is often difficult to avoid if the

diurnal range of temperature is considerable, there will inevitably result distortions of the surfaces of equal atmospheric density, which will affect the total refraction differently by day and by night.

Much has been written, and a certain amount done, in discussion of sunrise and sunet effects on transit observations. The contributions to this problem in the present volume consist of observations in the period 1906 to 1908, and a special series in 1920. The results agree in indicating that transits near the time of sunset are observed relatively earlier than those near sunrise, by about .06 sec. No definite evidence is adduced to show whether the effect is a periodic diurnal one depending definitely on the hour angle of the sun. The general results were confirmed by the San Luis observations, but contradicted by investigations at the U.S. Naval Observatory. This is one of the problems awaiting definite solution.

The bulk of the volume, of course, consists of results of various observations for right ascension and declination. Many of these have already served the particular purpose for which they were undertaken. It is a distinctive feature of meridian circle observations that their value increases with the lapse of time, and the making available in permanent form of this series is a distinct contribution to position astronomy. R. M. S.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Astronomy by Radio

Oscar Lee Dustheimer, Professor of Astronomy at Baldwin Wallace College, Berea, Ohio, will give a Series of Astronomical Talks over WEAR Cleveland. The following subjects will be broadcast: A Perpetual Calendar, Venus as an Abode of Life, Easter, Habitability of Mars, Biblical Astronomy, and Our Suns and Others. The first of these talks was given on January 22, at 7.45 p.m., E.S.T.

Two More Fire-Balls

On the evening of December 29, 1925, a brilliant fire-ball was seen by residents in Ottawa and in other parts of eastern Ontario, as well as in some of the eastern United States. Dr. Ralph DeLury, of the Ottawa Observatory, collected a considerable number of reports of the phenomenon, and many were gathered by Harvard Observatory. These are all in the hands of Dr. W. J. Fisher, of the latter place, who will prepare a paper on the meteor. We expect to publish an account of it in a future number.

Mr. A. G. McDonald, of Toronto, reports that at 11.05 p.m., January 16, when on the Dundas St. Bridge he observed a very bright meteor pass from north to south immediately over his head. He could observe it over about 15 degrees of its path. No noise was heard, though there was considerable noise about at the time.

The New Moon Rising in the West Again

A friend draws my attention to the astronomical conditions demanded in the following little poem by Wilfrid Gibson, which appeared in the *London Observer*.

WINTER MOONRISE

A flake of crystal in the frosty amber,
The new moon quickens through the afterglow,
Till, clear of the black fret of branches sailing,
Its cold light glances on the hoar ice mailing
The little tarn below
The marble peak of snow.

Immortally through numberless Novembers
In crystalline renewal the moon shall rise,
And her cold lamp, through heaven serenely sailing,
Light peak and tarn, and yet be unavailing
To pierce the dark that lies
On these frail mortal eyes.

The poem requires a careful reading in order to comprehend its meaning, but I think it is substantially as follows.

The author aims to describe a moonrise in winter. The crescent moon, like a "flake of crystal" in the west, grows brighter as the twilight fades, and at the same time it rises until it sails clear of the dark branches of the trees and shines upon the white icy covering of the little mountain lake.

Through the countless Novembers of the coming years this renewed crystalline crescent moon shall rise and shall sail through the heavens, dispensing her cold light upon mountain peak and lake—but unable to pierce the dark surface of our eyes and reveal the secrets beneath.

Very pretty, but entirely untrue to nature. Perhaps on Mount Parnassus the moon rises in the west. It reminds me of the story told by Dr. Aitken, which I give in his own words.[1]

One Saturday evening, several years ago, I was standing in front of the Lick Observatory with a party of people who had come to look through the 36-inch telescope. The sun was just setting behind the hills south of Mt. Tamalpais, and as it disappeared, the slender crescent of the moon, less than two days past the new, appeared low in the sky south of the sunset point. One of the visitors, after watching it a moment, turned with the question: "Why is it that the new moon rises in the west, while the full moon rises in the east?"

As soon as I recovered, I explained as tactfully as I could that the moon, whether full or new, always rose in the east, but that when it was just past the new-moon stage it rose very near the sun, and after sunrise, and therefore could

[1]Adolfo Stahl Lectures, p. 76.

not be seen until the sun had set, by which time, of course, it was itself approaching the western horizon. But my tact or my explanation, or both, were unequal to the occasion, for when I had finished, the visitor replied with great dignity, "Well! That is the way it may do here, but in Humboldt County the new moon always rises in the west!"

Eleven Comets in 1925

In *Science Service* is given an account of the discovery of a new comet, as follows:

The eleventh comet of the year was discovered by G. E. Ensor, an amateur astronomer at the Cape of Good Hope, where a southern branch of the British Royal Observatory is maintained. It was in the constellation of Reticulum, the net, and moving northeast into the neighbouring constellation of Horologium, the clock, according to Dr. Harlow Shapley, director of the Harvard College Observatory. Both of these constellations are far south of the equator and can be well seen only from southern latitudes. Its motion, however, may bring it into view in the southern United States, and, as it is now of the eighth magnitude, it could be seen with small telescopes.

With eleven comets discovered since January 1, some of which were new while others were old friends returning for one of their periodic visits, 1925 will go down in the history as one of the most prolific years for comets on record. The nearest approach in recent years to this record was in 1921, during which seven were found, but two of these were doubtful objects whose cometary nature was not fully established. All found during the year, with the exception of the new one, have been observed by many astronomers and their orbits have been accurately computed. Doubtless other southern observatories will make observations of the new visitor, and allow its path to be calculated.

This is the second comet in 1925 to be discovered in South Africa, for on March 24, William Reid, an amateur astronomer living near Cape Town, discovered a comet which now bears his name. Another South African discovery of the year was that of a new star in the constellation of Pictor by R. Watson, another amateur astronomer, and a telegraph operator by profession, who noticed a strange star in the heavens when he was going to his work in the early morning. Two other of the year's comets were found by Americans, Professor George Van Biesbroeck, of the Yerkes Observatory, and Leslie C. Peltier, an amateur astronomer; while two others were found in Russia.

It is only coincidence that has brought this large number of comets near the earth this year, and no dire results may be expected from them. In earlier times, however, comets were supposed to portend great catastrophes, so it is a matter for thankfulness that most people no longer believe in these old superstitions.

PRESENT CONDITION OF FORMER NOVAE.

Among the multitude of celestial objects none are more wonderful than the new stars. How a body which can be detected only with difficulty in the telescope, or indeed which cannot be seen at all, is able in a few days to rise to a brilliance rivalling the brightest of the stars in the sky, and then in a few weeks to fade away again, is truly a mystery. The late Professor E. E. Barnard usually had a number of past Novae on his observing list and at short intervals would report their condition. His mantle seems to have fallen upon Dr. W. H. Steavenson, who in a recent number of *Monthly Notices* gave his observations of a number of these remarkable objects, in continuation of his previous work. Usually he employed a 6-inch Wray refractor with powers of 120 and 280.

Nova Cassiopeiae (1572), or Tycho's star, was sought for in the approximate position known to have been occupied by it. Two stars near this position have been carefully examined, but no change in them has been certainly found; though it may be that neither one is Tycho's star.

Nova Ophiuchi (1848, mag. 5) was observed on 23 nights from May to September. Its magnitudes were from 12.1 to 12.6. There is further evidence of a variability with a period of about 40 days.

Nova Cygni (1876, 3rd mag.) was observed on 8 nights between July 21 and October 23. Now of magnitude 14.7.

Nova Persei (1901, 1st mag.) was observed on 55 nights between July 15, 1924, and March 23, 1925. Its magnitude varied between 12.4 and 13.8, and the average brightness was much less than in 1918-19.

Nova Lacertae (1910, 5th mag.) was observed on 3 nights. For some years its brightness has not changed, its magnitude being 14.1.

Nova Aquilae (1918, 0 mag.) was observed on 37 nights between May 5 and October 22. The magnitude was pretty steady at 10.35, with possibly very slight variations. Its brightness is approximately the same as before its outburst.

Nova Cygni (1920, 2nd mag.) was observed on 31 nights between April 7 and October 23. Its magnitude fell from 11.7 to 12.7, and the brightness is still fading. Before the outburst the magnitude was lower than 15.

C. A. C.

MEETINGS OF THE SOCIETY

At Toronto

December 15, 1925.—The regular meeting was held in the Physics Building at 8 p.m., the Vice-President, Mr. A. F. Hunter, in the chair. The chairman announced the dates of the annual meeting and the "At Home" and spoke of the recommendation at the last meeting of the Council that the "At Home" hereafter be held at the beginning of the season in the autumn.

The following were elected members of the Society:

Miss Ethel M. Creiger, 5 Langemark Ave., Toronto.
Mr. W. H. Plow, 1295 College St., Toronto.
Mr. Thomas Ransom, 1079 Queen St. E., Toronto.
Mr. J. H. Baker, 147 Gladstone Ave., Toronto.
Miss Dorothy Stone, 523 Sherbourne St., Toronto.

The Asst. Librarian reported 120 periodicals received during the last two months. Dr. Chant mentioned the brightness of Venus and the close conjunction of Venus and the moon on the 18th December.

Dr. R. K. Young addressed the meeting on the subject "Weather Signs and their Scientific Explanations". Dr. Young explained that his subject was really "Weather Proverbs", distinguishing those which have some scientific foundation from those which are foolish and fanciful. He remarked that scientific forecasts predict for from twelve to thirty-six hours in advance, and over large districts rather than over small localities, and that it was often possible by observing certain conditions of the air and the sky for an amateur to make local predictions with a fair degree of accuracy over a few hours. He then referred to various proverbs and explained their scientific connection with the conditions of the atmosphere, colour of the sky, lateness of the spring and other phenomena, and mentioned others which seemed to have no scientific foundation; for instance, those dealing with the appearance of the moon.

Dr. John Satterly then addressed the meeting, describing his impressions of the Cambridge meeting of the International Astronomical Union. This union was formed under the auspices of the International Research Council, which was formed after the war, the different countries being represented on the basis of population. Dr. W. W. Campbell, the President of the Union in the inaugural address remarked that its purpose was to facilitate relations between astronomers wherever international relations are useful, and to promote astronomy in all its departments. Committees were chosen for the numerous Departments and the work for the next three years arranged by these committees.

Dr. Satterly emphasized the advantages to be gained by meeting noted astronomers from other countries at informal gatherings.

G. M. Bryce,
Recorder.

At London

December 11, 1925.—The regular monthly meeting of the London Centre was held in the Library of the Normal School on Friday, December 11, at 8.15 p.m., Dr. H. R. Kingston presiding.

Miss M. Caldwell and Miss V. Caldwell, 236 Tecumseh Ave., were elected members of the Society.

Dr. Kingston gave an interesting address on "A Month on the Moon". He stated that it would be necessary to leave the earth at a speed of seven miles per second to overcome the earth's gravitation pull, and if we were successful in making the trip we should approach the moon at the rate of one and one-half miles per second.

Dr. Kingston next described the many strange experiences we should have, and the peculiar phenomena we should see during our stay on the moon. There being no atmosphere, we should have to breathe the oxygen we were forehanded enough to take with us. We should weigh but one-sixth of our weight when on the earth, but we could run and jump more readily. There would be no diffusion of light, hence rapid changes from light to darkness.

The sky would appear very blue, and the stars would make a complete revolution in 29 days, and would be visible at all times. There would be 14½ days of daylight followed by 14½ days of darkness. Strangest of all, if we were on that side of the moon which faced the earth we should see the earth always in the same part of the heavens, and in size it would appear about 16 times the size of the sun.

It would be very quiet on the moon. There being no atmosphere, there would be no sound and no wind, and hence no oral speech. We should have to communicate by signs. Taking it all-in-all, we should likely be glad enough to return to the earth at the end of our month's visit.

Dr. Kingston's address was followed by a game of jumbled astronomical names which was much enjoyed, as were also the refreshments served by the ladies..

The annual meeting of the London Centre was held on the same date and in the same place as the above meeting.

The minutes of the last annual meeting were read and approved.

The secretary read his annual report, which, on motion of Messrs. Benson and Bowen, was approved.

The treasurer then read his annual financial statement showing a cash balance on hand of $43.17.

On motion of Messrs. Patterson and McKenzie, the treasurer's statement was received.

Mr. J. C. Middleton reported for the auditors that the treasurer's books and vouchers had been audited and found correct. On motion of Messrs. Middleton and Coleridge the treasurer's annual statement was adopted.

The election of officers was next proceeded with and resulted as follows:

President—H. R. Kingston, M.A., Ph.D., F.R.S.C.

Vice-President—Mrs. W. E. Saunders.

Secretary Treasurer—E. T. White, B.A., D.Paed.
Councillors: Rev. R. J. Bowen, F.R.G.S., T. C. Benson, Mrs. J. C. Middleton, W. A. McKenzie, E. H. McKone, B.A.

E. T. WHITE, *Secretary.*

AT MONTREAL

December 9, 1925.—The President Col. W. E. Lyman in the chair.

New members were elected as follows: Mrs. E. F. Walter, Mr. J. F. Donohue, Miss Violet Johnson, Mr. A. F. Waters, Dr. R. Kerry.

The speaker of the evening was Dr. F. Henroteau, Dominion Observatory, Ottawa. His subject was "Variable Stars of the Cepheid Type".

The Milky Way was thought by Aristotle to be an effect of our own atmosphere. Ptolemy and Democritus believed it to be due to many small stars as was proved to be true by Galileo. Sir Wm. Herschel first realized its vastness. A diagram of our galaxy (sometimes called the Sidereal Universe) was shown, explaining the more or less spherical distribution of the nearer stars in contrast to the strong concentration towards the Galactic plane of the many millions of stars comprising the greater part of the galaxy. The space-scale of the galaxy was given as 100,000 light years in diameter by about 1,000 light years in thickness.

Some atomic theory was briefly introduced to explain the presence of lines, due to ionized atoms, in the spectra of giant stars. Approximately one giant star in every thousand shows the regular succession of light changes, accompanied by changes in radial velocity of the luminous vapours and in the intensity of the ionized spectral lines, characteristic of the variables of the Cepheid type.

A Cepheid variable was compared to a vast furnace of the diameter of the orbit of Mars; heated to a temperature of 20 million degrees and throbbing with clock-work precision in periods from a few hours to several days.

The fact that in one arm of the Milky Way almost no Cepheids are to be found, suggests the presence in the other portions of the galaxy of some unknown force operating to induce pulsation.

In conclusion the spiral nebulae beyond the confines of our galaxy were referred to, and the fact that they contain Cepheid stars—although only of apparent magnitudes 20 to 22—has enabled Dr. Hubble of Mt. Wilson to form estimates of their distances. These distances are of the order of 1,000,000 light years at the minimum, the upper limit being beyond conjecture.

It is a matter of great satisfaction that some twenty observatories variously situated around the earth are now co-operating in a programme of Cepheid Variable observation, the Dominion Observatory having been selected as the centre to which all records will be sent for compilation and discussion.

A hearty vote of thanks was offered the speaker by Mr. W. T. B. Crombie.

Mr. H. E. Asbury drew the attention of members to the wealth of information in the "Observer's Handbook" and urged its more careful study.

Dr. A. S. Eve objected strenuously to the use of the word *Universe* in any other sense than as the sum total of everything that exists, quoting from the Oxford Dictionary where the interesting entry is as follows—Universe—All existing things; the whole Creation (and the Creator).

A. V. DOUGLAS, *Secretary.*

The Royal Astronomical Society of Canada

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